

# On the angular momentum of the neutron star

Zakir F. Seidov \*

Shemakha Astrophysical Observatory, Shemakha 373243, Azerbaijan,  
Research Institute, College of Judea and Samaria, Ariel 44837, Israel

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## Abstract

This is a more or less exact English version of the short note published some 33 years ago in Russian. Still it is of some interest and not only from the historic point of view. No attempt was made to add new references or upgrade the text.

It is shown that the mass loss due to rotation-driven hydrodynamical instability during the catastrophic collapse of the star is small. Neutron star is formed with a large rotational kinetic energy and the spin-down takes place in the following life of neutron star as a pulsar.

## 1

The Crab pulsar NP0532 with the smallest pulsation period .033 sec, if it is connected with 1054 year SN, is also one of the youngest pulsars, neutron stars (n.s.), remnants of SN explosion. If the pulsation period NP0532 is the rotation period [1] then n.s. with rotation period  $T = 0.033$  sec, mass  $M \approx M_{\odot}$  and radius  $R \simeq 10^6$  cm has rotational momentum less than one-tenth the solar momentum. Evidently or n.s. lost his momentum at birth or the momentum loss took place during n.s. life. In [2], it is claimed that the large momentum and mass loss is possible during the catastrophic hydrodynamical instability. We reconsider the problem and show that momentum loss is small and mass loss is negligible [11].

## 2

We assume that the mass ejection of the rotating and contracting star takes place at the star equator. Then for the momentum loss we have expression

$$dL = \alpha^2 R^2 \omega dM,$$

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\*e-mail: zakirs@yosh.ac.il

where  $\omega$  is the rotational angular velocity,  $R$  is the equatorial radius, and we assume that the mass element leaves the star at distance  $\alpha R > R$ , due to e.g. magnetic forces confining the matter. Moreover we assume that all the way during the contraction, the injection condition

$$\omega^2 = G M / R^3$$

holds, where  $G$  is the gravitational constant. Also we write the angular momentum relative the rotation axis in the form

$$L = k M R^2 \omega,$$

where  $k$  is structural parameter depending on density distribution inside the star, and get finally:

$$\begin{aligned} \frac{M}{M_0} &= \left( \frac{R}{R_0} \right)^\beta, \\ \frac{L}{L_0} &= \left( \frac{R}{R_0} \right)^{3\beta/2+1/2}, \\ \frac{\omega}{\omega_0} &= \left( \frac{R}{R_0} \right)^{\beta/2-3/2}, \\ \beta &= \frac{k}{2\alpha^2 - 3k}. \end{aligned}$$

### 3

The values of  $k$  were calculated for spherical configurations in [3], and for configurations at the state of rotational instability in [4]. In all cases  $k < 1$ ; for instance, for  $n = 3$  polytrope case (which is likely the case for star losing his gravitational stability), at  $\alpha \approx 1$  and taking into account the small deviations from the spherical symmetry, we have  $k = 0.038$ ,  $\beta = 0.02$ .

More particularly for a star with  $M \approx 2 \cdot 10^{33}$  g, and  $L = 4 \cdot 10^{48}$  erg sec, the condition of rotational instability commences first at  $R_0 = 2.1 \cdot 10^7$  cm,  $\omega = 1.2 \cdot 10^2 \text{ sec}^{-1}$ . After contracting to state of n.s. with  $R = 1.2 \cdot 10^6$  cm, we get (assuming  $\alpha = 1$ ):

$$\omega_{n.s.} = 8.8 \cdot 10^3 \text{ sec}^{-1}, \quad T_{n.s.} = 7 \cdot 10^{-4} \text{ sec}.$$

### 4

For n.s. formed from a star with mass  $M_0$ ,  $\omega_{n.s.} \propto \omega_0 R_0^{3/2} \propto M_0^{1/2}$ , that is the angular velocity of "new-born" n.s. increases with increasing  $M_0$  and does not depends on  $L_0$ . Also  $M_{n.s.} \approx M_0$  because the mass loss is negligible in all cases. Taking into account the magnetic forces ( $\alpha > 1$ ) leads to even lesser values of the momentum and mass loss.

We conclude that the rotational instability can not be an effective mechanism of the momentum and mass loss at n.s. birth, see also [5,6,10].

Therefore the neutron star (pulsar) is formed with a strong rotation and the momentum loss (spin-down) takes place during the pulsar's life. Of course we do not take into account the possibility of other mechanisms of momentum and mass loss due to e.g. explosions or any other mechanisms [6,7] due to uncertainty about their efficiency.

As it is known [7,8,9], the different mechanisms of pulsar spin-down lead to different dependences of  $dT/dt$  on time  $t$ . If we assume for evaluation purposes that  $dT/dt = c \cdot T$ , then we get  $c = 10^{-10} \text{ sec}^{-1}$ , which is close to value observed at the present.

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Z.F. Seidov

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